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Examination and Analysis of Equipment Involved in Mr. Justin Moore's June 8, 2017, Fall Incident

United States District Court
Northern District of Texas
San Angelo Division

Cause No. 6:19-CV-00038-H

Justin Moore and Judith Moore vs DB Industries, LLC, et al.

Prepared For:

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STATE OF TEXAS
L. CLARK McDONALD
84732
LICENSED
PROFESSIONAL ENGINEER
11/13/20

Prepared by: L. Clark McDonald, Ph.D., P.E. / Associate

Date: November 13, 2020

1 BACKGROUND

On April 13, 2020, Structural Integrity Associates, Inc. was retained to provide technical assistance in evaluating equipment associated with a fall involving Mr. Justin Moore. The fall incident reportedly occurred at Tower 41 at the Goldthwaite Wind Energy facility located at 418 East FM Rd 572 E, in Goldthwaite, Texas. The facility is owned and operated by Invenergy Wind, LLC.

According to the available information, Mr. Moore was performing work at Tower 41 with a co-worker, Mr. Cory Wade. After completing their work in the upper region of the tower, Mr. Wade reportedly descended to the bottom of the tower as Mr. Moore waited at the yaw deck. The tower consists of a lower section (above ground level but below the base deck) that is about 30 feet tall. A stairwell is used to access the interior of the tower, and a vertical (fixed) ladder is used to climb about 20 feet further to reach the base deck. From the base deck, a separate vertical (fixed) ladder is used to climb to the middle deck, the saddle deck, and the yaw deck; the yaw deck is located just beneath the nacelle, which contains the mechanical equipment used to generate electricity; this arrangement is shown schematically below. The upper ladder is equipped with an IBEX climb assist system that is intended to assist climbers moving up or down the ladder.

When Mr. Moore was ready to descend from the yaw deck, he reportedly attached the cable sleeve (the Lad-Saf X3) to the cable and tested it to make sure that it locked properly onto the cable when moving down. He stated that when he gets ready to come down, the hatch door is closed so he can maneuver himself, and that he connects the Lad-Saf to the cable and tests it and then steps off of the hatch and opens the hatch to go down.

Mr. Moore stated that they also have an IBEX pendant, and before climbing they connect that pendant to the IBEX belt. He stated that you have to come down a little bit before connecting the IBEX pendant, and that they (the workers) have to lean down to initiate some weight on the IBEX pendant to engage it, and at that point you can initiate the motor on the climb assist system. He said that part of their process for using the IBEX system was to inspect the belt, and visually check the weld, if you could see it, by rotating the belt through a cycle. He stated that the IBEX has basically three settings, and he would normally use the maximum setting.

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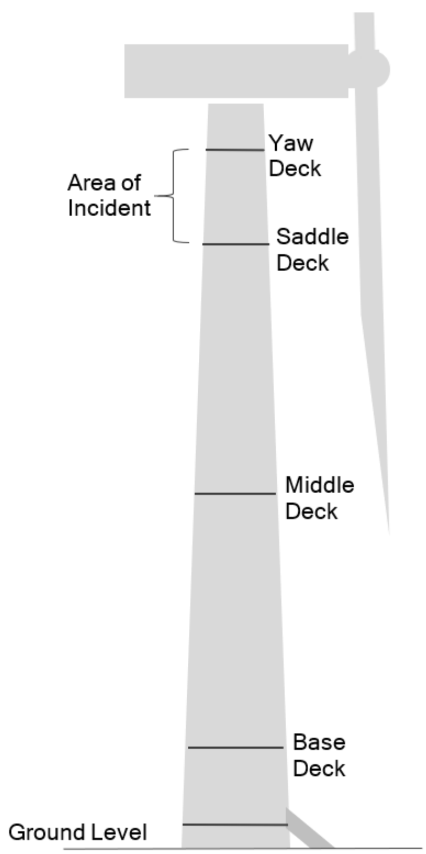
Mr. Moore stated that before he reached up to close the hatch, he had both hands and both feet on the ladder rungs, and that he was wearing gloves and his hard hat. He said that he had initiated the IBEX climb assist system, but he realized the hatch was open, so he reached back up to close the hatch, and then reinitiated the IBEX. He indicated that his recollection was that he closed the hatch with his left hand, and at some point after that, on his descent, all he knows is that the IBEX belt snapped, and he doesn't recall much after that. He reported that it happened immediately after he pulled down the hatch, and it might have been after taking a step down. He reported feeling a violent movement when the IBEX belt broke.

After the fall, Mr. Moore described coming to a stop and not knowing what happened, and stated he was just hanging there and he noticed that the IBEX looked like it had broken. Mr. Moore stated that he had no idea how far he had fallen until he was told by one of his coworkers, and he doesn't know how they determined the distance. He said the he remembers the sound of the IBEX belt falling down the tower, and hearing the Tuf-Tug (steel) cable popping against the rungs of the ladder, and he believes there was some of the IBEX belt stuck above him as well. He reported that he was close to the saddle deck and that the Lad-Saf was stuck on the cable, and he radioed Cory to tell him that he was stuck, so Cory sent up another Lad-Saf and Mr. Moore was able to climb down safely.

Schematic of Tower 41
(Not to Scale)



2 EXAMINATION OF THE INCIDENT SITE

2.1 Tower 41

Tower 41 at the Invenergy wind farm facility near Goldthwaite, Texas, was visually examined on October 6, 2020. As described in Section 1, the tower access door is located at the top of an external stairwell (Figure 1). Once inside, a fixed vertical ladder, approximately 20 feet in height, is used to access the base deck. The top of this ladder ends a few feet above the base deck elevation, and from the base deck a separate fixed vertical ladder extends to the middle deck, the saddle deck, and the yaw deck (Figures 2 and 3). The ladder used to access the base deck is equipped with a Tuf-Tug cable for attaching cable sleeves when climbing, but is not equipped with a climb assist system (Figure 3, lower image).

The ladder that is used to climb from the base deck to the yaw deck is equipped with an IBEX climb assist system and a Tuf-Tug cable; the IBEX polymer belt and the Tuf-Tug steel cable are routed side-by-side near the middle of the ladder (Figure 3, upper image). The IBEX system has a motorized drive unit that is attached to the bottom of the ladder, and a portable control unit that attaches to the side of the base of the ladder (Figure 2). The Tuf-Tug cable is also attached to the bottom rungs of the ladder. The IBEX belt consists of a full loop that passes through the drive unit at the bottom and around a pulley located at the top of the ladder; operation of the system produces a load on the belt that lifts up on the pendant (attached to the climber), regardless of whether the climber is ascending or descending.

2.2 IBEX Belt and Tuf-Tug Cable

On the day of the site visit, access to locations above the base deck were not permitted, although photographs of the upper region of the ladder were taken as part of Invenergy's incident investigation. The IBEX belt and Tuf-Tug cable that were installed in the tower were replacement components, as the failed IBEX belt and the Tuf-Tug cable involved in the fall event had been removed from the tower. The involved belt and cable were located at Invenergy's site, and were photographed prior to being transported to ESI's laboratory in Dallas, Texas (Figure 4). The belt and cable had reportedly been stored on a pallet after removal from the tower. In addition, the stored belt did not include the segment of belt containing failure location, as the failed ends had been previously removed from the belt.

2.3 IBEX Belt Welding Equipment

During the Invenergy site visit, a kit used to weld IBEX belts was provided for examination (Figures 5 and 6). When installed into a tower, the IBEX belts are formed into a loop by welding two ends together. The welding kit presented by Invenergy was described as a typical kit, but was not confirmed as the kit that was used to weld the subject IBEX belt.

3 EXAMINATIONS AT ESI LABORATORY - AUGUST 19, 2020

3.1 Harness and Gloves Worn by Mr. Moore

Various items associated with the fall incident were visually examined at the ESI Laboratory facility in Dallas, Texas, on August 19, 2020. These items included the harness that Mr. Moore was wearing (Figure 7). The harness was identified as a DBI (Sala) Exofit Model 1113192, Lot No. 2790214, and Serial No. E004035007A8A1A. The harness did not exhibit any obvious indications of damage or broken parts.

The gloves that Mr. Moore was wearing were also available for examination (Figure 8). The gloves were manufactured by Mechanix and indicated as the "MPACT" style. The gloves exhibited some degree of wear, but no evidence of tears or holes.

3.2 Extracted Segment of the Failed IBEX Belt

A segment of the IBEX belt that contained the failure location was available for examination; the two pieces making up the failed segment had been cut from the overall IBEX belt and transported to the ESI facility independent of the remainder of the belt (Figure 9). The belt examination included the use of a stereo microscope to look at surface features at low to intermediate magnifications, and images were taken by ESI personnel using a digital camera attached to the stereo microscope.

Close visual examination of the failure region revealed that the failure occurred at a weld (Figures 10 and 11). On one side the fiber core was frayed and appeared to be slightly dirty, and on the other side the fiber core was intact and with a cleaner appearance. At the failure location, the separation occurred in a stepped manner, with partial transverse separations at two (offset)

locations, and a longitudinal split that extended about three inches along the length of the belt (Figure 12). The polymer exterior was also permanently bent in the area of the failure.

3.3 Deployed Lad-Saf X3 Sleeve

Mr. Moore's Lad-Saf X3 sleeve was available for visual examination at the ESI facility (Figures 13 and 14). Markings on the sleeve identified it as Model No. 6160054 with Serial No. 0005580. The sleeve included an attached carabiner, and the locking arm (energy absorber) was deployed (in a stretched condition). Aside from the deformed energy absorber, which was stretched to a length of approximately 5-3/8" (pin-to-pin) and slightly twisted, no other components exhibited evidence of deformation or cracking.

During the August examinations at ESI, the X3 sleeve was X-rayed to check for internal damage. The X-ray images taken by ESI did not reveal any internal broken components. No other testing was performed during the August examination event.

4 EXAMINATIONS AT ESI LABORATORY - OCTOBER 7, 2020

4.1 IBEX Belt and Tuf-Tug Cable

The IBEX belt segments and Tuf-Tug cable stored at the Invenergy site were transported to the ESI Laboratory in Dallas, Texas (Figure 15). Although the IBEX belt would have been installed in the tower as a single loop (after welding the ends together), the belt was in multiple sections as a result of cuts that were made subsequent to the fall event (Figure 16). At least one of the cuts was identified as a match to a cut on the shorter failure segments. The belt was not uncoiled, but visual examination of the segments revealed at least two locations where deformation was evident (permanent bends) (Figure 17). The position of the weld at the time of the failure (relative to the Tower 41 ladder) was not determined.

The upper end of the Tuf-Tug cable was laid out in order to measure the position of a marked kink in the cable (Figure 18). The cable was marked at five-foot intervals using yellow electrical tape, and the kink was determined to be approximately 25 feet below the upper fitting. The upper and lower ends of the cable were placed side-by-side and visually examined and photographed (Figure 19). The upper region of the cable was darker in color due to a slight residue of oily

substance and deposits (dirt, debris) that was stuck to the surface. The diameter of the upper region of the cable was measured in multiple locations and at each location the measurement was consistent with 3/8" diameter cable (Figure 20). In addition, examination of one end of the cable revealed that it was 7x19 construction.

Hardware used to attach the Tuf-Tug cable to the tower ladder was stored and transported with the cable (Figure 21). The hardware components were visually examined and found to be intact with minor indications of wear.

4.2 Testing of Two Lad-Saf X3 Sleeves

A primary goal of the October examination event at ESI's Dallas laboratory was to conduct a destructive examination of the subject (deployed) Lad-Saf X3 sleeve. However, prior to beginning this work, multiple tests were performed on the subject sleeve, and for comparison, two tests were performed on an exemplar Lad-Saf X3 sleeve (the exemplar had not deployed so there was no deformation in the energy absorber). The subject sleeve was first tested by performing several manual manipulations in order to assess the movement of the locking cam. After these tests, both the subject and exemplar sleeves were tested on a section of Tuf-Tug cable using a temporary setup wherein the lower end of the cable from the tower was attached to the ceiling structure and loaded with 40 lbs of tension (Figure 22).

In one of the manual manipulation tests in which the locking arm was loaded laterally with respect to the sleeve body, the cam did not move freely within the sleeve until the lateral load on the locking arm was released. In the other manual tests performed on the subject X3 sleeve, the sleeve appeared to function in a normal manner. The lateral load test result is discussed further in the Discussion section of this report.

The subject X3 sleeve was tested on the vertical cable setup by moving it up and down, releasing it, disengaging it, etc., and the sleeve, even with a deformed locking arm, engaged and released the cable in a normal manner (Figure 23). When the exemplar X3 sleeve was tested in a similar manner on the vertical cable, the sleeve engaged the cable in a normal manner (Figure 24). When the subject sleeve was held and manually accelerated down the cable with the locking arm held in the up position, the sleeve did not engage the cable. When the exemplar X3 sleeve was tested in a similar manner, it also did not engage the cable. The locking arm on the X3 sleeve was then taped into the up position and a 10 lb weight was attached to the carabiner. When the

weight was raised up and then dropped, the sleeve engaged the cable such that the weight then loaded the locking arm, stretching the tape (Figure 25). Overall the testing performed on both sleeves resulted in expected behaviors for the sleeves.

4.3 Disassembly and Examination of the Subject Lad-Saf X3 Sleeve

In order to further examine the individual components of the involved X3 sleeve, the rivets on one side of the device were ground off to permit disassembly of the sleeve (Figure 26). The exposed parts were removed sequentially and photographed (Figures 27 through 33). The internal parts were intact with no evidence of cracking. Small amounts of dirt or debris were observed on the surfaces of some parts, including the bushings and Teflon washer that guide the locking cam and locking arm components. The bushings also exhibited evidence of rubbing or scuffing on the edges (e.g., Figures 29 and 31). The locking cam surface that engages the cable exhibited witness marks (scuff marks or abrasions) that were consistent with the cam having engaged the cable (Figure 32).

Based on a visual examination of the removed parts, the only part that appeared to exhibit evidence of deformation was the energy absorber (locking arm) that had deployed by stretching and slightly twisting (Figure 33). The pin-to-pin length of the deformed arm was measured to be 5.368”.

5 DISCUSSION

Based on the information obtained from the site and equipment examinations, important details of the fall incident cannot be confirmed. Firstly, the IBEX belt was installed as a loop around fixtures at the top and bottom ends of the ladder. As the system operates, the belt loop rotates and the location of the weld changes. Because of this, and the limited amount of detailed information recorded immediately after the incident, the location of the weld within the loop when the weld failure occurred is not known. Since Mr. Moore was reportedly attached to the belt through the IBEX pendant, the location of the failing weld could influence the extent and manner in which the IBEX belt interacted with Mr. Moore during this event. This interaction could also have been affected by a portion of the belt being wrapped over the top of the ladder. However,

as the location of the weld at the moment of failure is not known, the details of the interaction between the IBEX and Mr. Moore cannot be determined.

With regard to the available physical evidence, none of the reviewed items confirmed the location or position of Mr. Moore when the belt failed. Although Mr. Moore described the event as occurring immediately or nearly immediately after he closed the hatch, he stated that he had no idea how far he had fallen until his coworkers told him, and he didn't know how his coworker determined the fall distance. Based on the distance from the top of the Tuf-Tug cable to the marked kink in the cable, presuming that the kink represented his final resting position, and accounting for the information indicating that the top of the ladder was located a few feet above the yaw deck, and that he was beneath the hatch located at the yaw deck, the maximum possible distance would have been about 20 feet. As a result of the fall, the energy absorber on the Lad-Saf X3 sleeve was stretched to a length of 5.368" (measured pin-to-pin), but the absorber was not fully extended.

The examinations performed on the IBEX belt, the Tuf-Tug cable, and the Lad-Saf X3 sleeve components that were involved in the fall incident revealed that the belt failed at a weld location, but did not identify a reason why the X3 sleeve would have permitted Mr. Moore to fall a distance of up to 20 feet. The exact reason that the weld failed on the IBEX belt is beyond the scope of this report, but the belt failure reportedly initiated the fall incident by causing Mr. Moore to lose his grip on the ladder. A physical defect associated with the X3 sleeve was not identified, and the testing performed on the sleeve, even after the energy absorber had deployed, revealed that it performed as expected, with the possible exception of one of the lateral load tests conducted by an ESI technician.

The lateral load testing performed by ESI did not appear to be relevant for several reasons. First, the test was performed on a sleeve that had been involved in a fall event, such that the locking arm was deformed (stretched and twisted) as a result of the loading event. Therefore, this test was not necessarily indicative of how the sleeve would have performed if the same test had been performed before the fall incident. Secondly, in order for a side-load to have been applied to the locking arm during the fall event, the sleeve would have to have already been engaged with the cable. If the sleeve was not already engaged with or locked onto the cable, a lateral load on the locking arm would have caused the sleeve to rotate relative to the cable. Finally, Mr. Moore reportedly maintained three points of contact with the ladder while closing the hatch and climbing,

and so there is no indication from Mr. Moore as to why or how an abnormal loading could have been applied to the sleeve. For these reasons, the lateral load testing did not provide any information to help explain how or why the sleeve could have allowed Mr. Moore to drop an abnormal distance.

Overall, the subject Lad-Saf X3 sleeve performed as expected during the laboratory tests. When moving the sleeve up and down the cable by hand, the sleeve locked onto the cable when moving down or when dropped, and released from the cable when raised. One test in which the locking arm was held up while manually accelerating the sleeve downward did not result in the sleeve locking onto the cable. However, the same test performed with an exemplar (undeployed) X3 sleeve produced the same result. The most likely explanation for these results is that the appropriate downward acceleration for activation (approximately 0.7 to 1.0 times gravitational acceleration, or “g’s”) could not be manually produced in either case. When both sleeves were held up and dropped, so that the downward acceleration was close to that produced on a free-falling object under normal gravitational load, the sleeves locked onto the cable as intended. When the subject sleeve was tested by taping the locking arm in the up position (so that it could not activate the locking cam), and attaching a 10 lb weight to the carabiner, then dropped, the sleeve activated and locked onto the cable, stopping the sleeve and causing the weight to fully load the locking arm and stretch the tape. Based on the testing performed, even the previously deployed Lad-Saf X3 sleeve performed as intended during the laboratory testing at ESI.

5.1 Supplemental Testing

In order to obtain additional information relevant to the fall incident, three tests were conducted by 3M staff on Friday, October 30, 2020. These tests were reportedly performed at the 3M test facility in Red Wing, Minnesota, in accordance with a test protocol developed by Mr. Greg Small. The testing was observed virtually using a Microsoft Teams connection. Each of the tests was conducted using X3 sleeves with pre-October 2016 energy absorbers, and in each test the sleeve was attached to a 3/8-inch diameter, 7x19 steel cable (approximately 20 feet in length) installed within the test bay. For two of the tests, loads were measured using a calibrated load cell, and for each test the sleeve was positioned at a different location on the cable.

One test was performed by slowly loading an exemplar sleeve while recording the peak load at approximately 1/2-inch displacements until the energy absorber was substantially extended. Another test was performed by a dropping a 220-pound anthropomorphic mannequin fitted with

clothes, boots, a vest, and harness (with a total weight of approximately 245 pounds), with the harness attached in a normal manner to an X3 sleeve connected to the test cable. A final test was performed by installing a cable loop between the mannequin and a new exemplar sleeve, and dropping the mannequin such that it could travel approximately 16-1/2 feet before engaging the X3 sleeve (the vertical clearance within the test facility did not permit a drop of 20 feet).

The results of the static (slow load) test provided displacement of the system (sleeve, cable, and support) as a function of load up to 3,100 pounds. The cable was slightly kinked at the location where the sleeve was attached during this test, and the final dimension of the energy absorber after the test was 5.938”. The sleeve was also reported to have slid 1.25” on the cable during the test.

The first drop test resulted in the sleeve traveling 3.88 inches before locking on to the cable and a partial deployment of the energy absorber on the X3 sleeve that was measured to be approximately 5 inches. As a result of this test the cable was kinked in a similar manner to that which resulted from Mr. Moore’s fall incident (Figure 34).

The extended drop test resulted in a full deployment of the energy absorber on the X3 sleeve that was measured to be greater than 6 inches. In addition, this drop test resulted in a higher degree of damage to the cable in the location where the sleeve was attached in comparison to the kink caused by Mr. Moore’s fall incident (Figures 35 and 36). Measurements during the testing indicated that the sleeve slid approximately 2 to 3 inches down the cable during the loading event, thereby absorbing additional energy from the falling mannequin. Damage to the cable included excessive kinking and broken wire strands. Finally, the harness worn by the mannequin in this test, which was the same model harness worn by Mr. Moore, sustained partial tearing of the straps at the leg loops on each side of the mannequin. The peak load measured during this test was approximately 4,200 pounds.

The drop tests performed suggest that Mr. Moore’s fall was consistent with a normal sleeve engagement event rather than an abnormal event of extended distance. This is based on the measured energy absorber extension on Mr. Moore’s X3 sleeve being more consistent with the extension measured on the X3 sleeve put through the first drop test, and the observed damage to the cable and harness that occurred during the 16-1/2 foot drop test, but which was not observed in association with Mr. Moore’s fall event.

6 CONCLUSIONS

- The IBEX belt failure occurred at a weld location within the belt. The location of the weld within the climb assist system loop at the time of the failure was not identified through the available information. The cause of the weld failure is outside of the scope of this report.

- The Lad-Saf X3 sleeve involved in the fall incident performed in an expected manner during testing performed by ESI Laboratory. In addition, with the exception of the energy absorber (locking arm), which is designed to deform during a fall arrest event, visual examination of the sleeve's internal components revealed no indications of cracking or damage that would have rendered the sleeve inoperable. In addition, no material issues were identified with regard to the sleeve or its internal components.

- Although details of Mr. Moore's fall event are unknown, including the location of the weld when the IBEX belt failed, testing performed on exemplar sleeves suggests that Mr. Moore's fall was consistent with a normal sleeve engagement event rather than an abnormal event of extended distance.

7 REVIEWED DOCUMENTS

Documents that were reviewed during the course of this work include the following:

- DBI Produced Documents (Including Manuals, Drawings, Test Reports, Emails and Photos)
- Safeworks Produced Documents (Including Manuals, Reports, Photos, and Procedures)
- Invenergy Produced Documents (Including Reports and Photographs from the Incident)
- ESI Laboratory Photographs and Videos
- Spectrum Forensics' Report, "Justin Moore Fall Incident Investigation", dated October 14, 2020
- Ellis Litigation Support's Preliminary Report dated October 14, 2020
- Deposition of Mr. Justin Moore
- Deposition of Mr. Rick Miller
- Data, Reports, and Photographs from 3M's October 30, 2020 Testing of X3 Sleeves

Figure 1. View of the base of Tower 41 at the Invenergy wind farm near Goldthwaite, Texas (upper image) and close view of a manufacturer's label on the inside wall near the base deck (lower image).

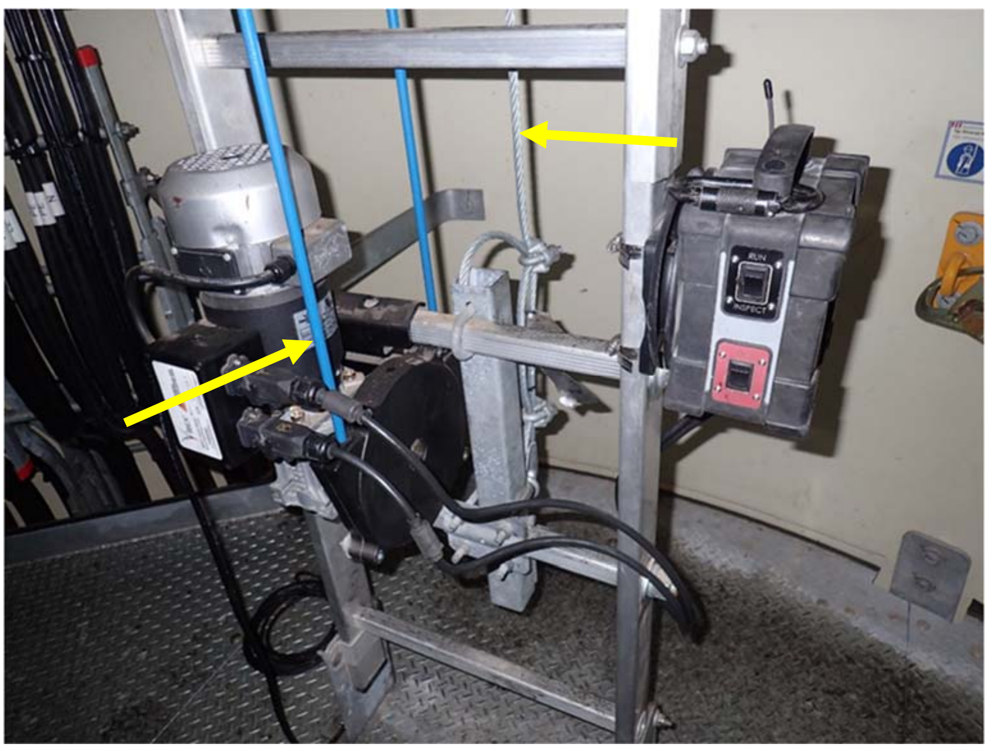
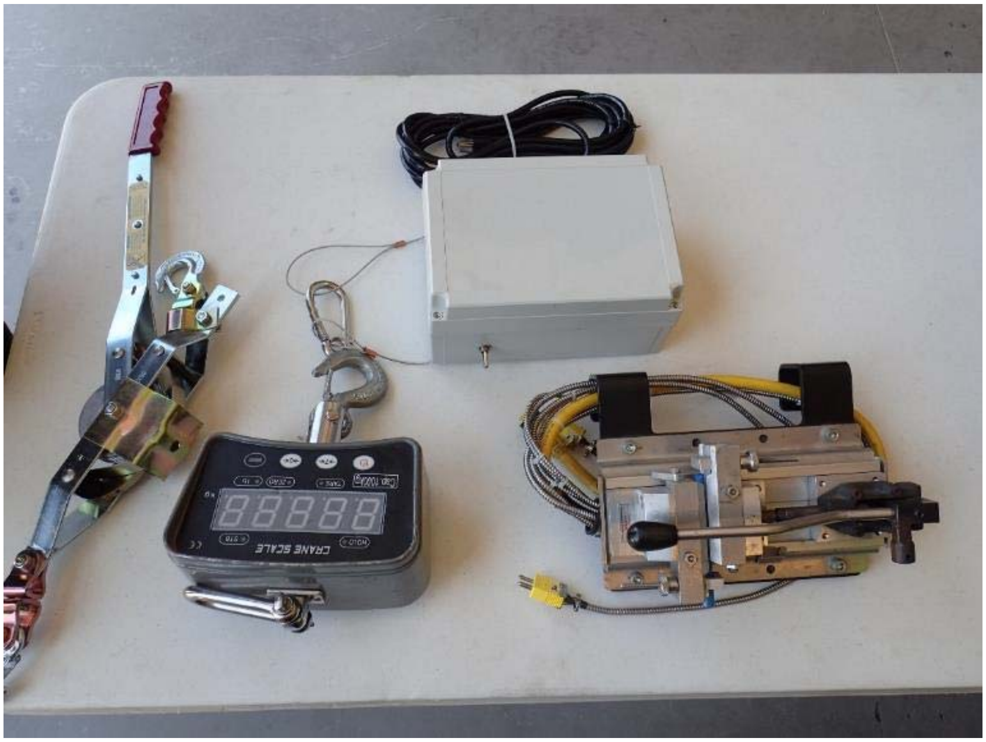


Figure 2. Views of the bottom of the vertical, fixed ladder at the base deck of Tower 41. In the lower image, the left arrow indicates the location of the IBEX climb assist belt, and the right arrow indicates the location of the Tuf-Tug cable that the climbers' sleeves attach to.

Figure 3. Views of the tower ladder looking up from the base deck (upper image) and the top of the base deck access ladder (lower image). In the upper image, the IBEX belt and Tuf-Tug cable are visible at the middle of the ladder. In the lower image, the hatch door is closed, and only a Tuf-Tug cable is present (this ladder, which is approximately 20 feet in height, is not equipped with a climb assist system).

Figure 4. Views of the Ibex belt (upper image) and Tuf-Tug cable (lower image) that were involved in the fall incident. These items had reportedly been stored, on the pallet shown, at the Invenergy wind farm site.

Figure 5. Views of an IBEX belt welding kit owned by Invenergy. This kit was available for visual examination, but not confirmed as the welding kit used to install the belt involved in the fall incident.



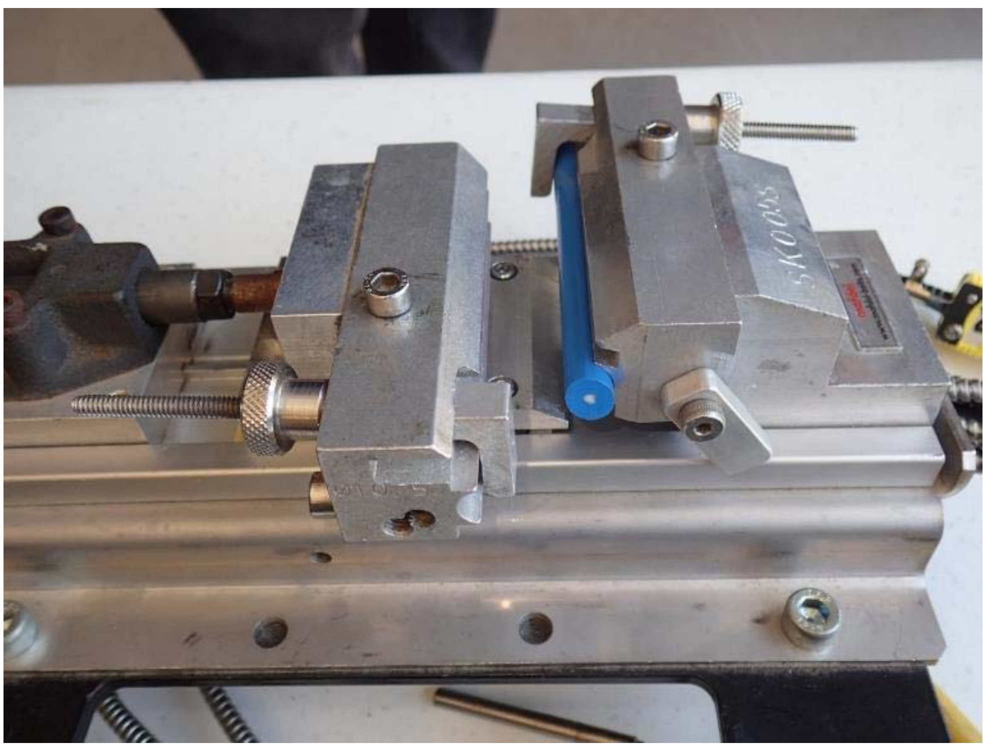
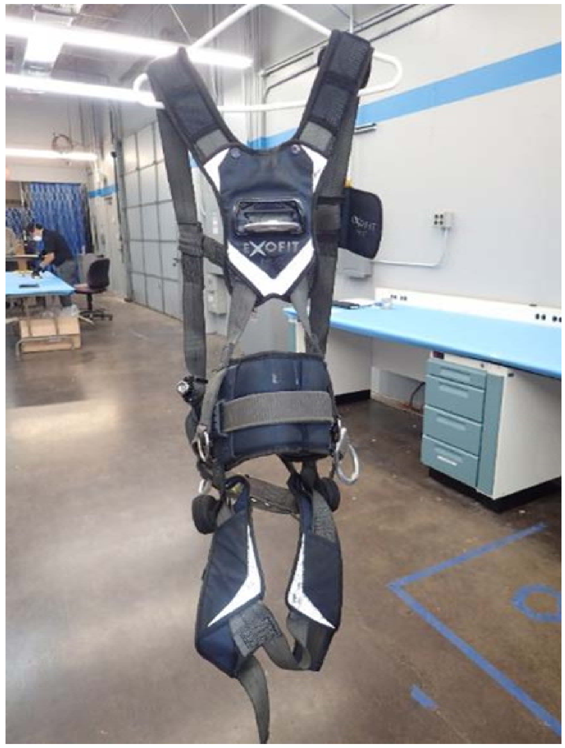


Figure 6. Additional views of components in the welding kit presented by Invenergy.



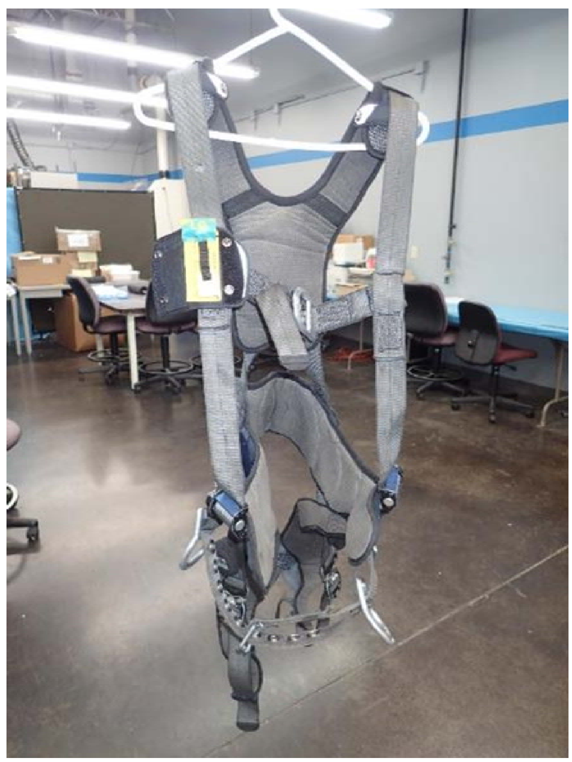


Figure 7. Views of the harness that Mr. Moore was reportedly wearing at the time of the fall incident.

Figure 8. Views of the gloves that Mr. Moore was reportedly wearing at the time of the fall incident.

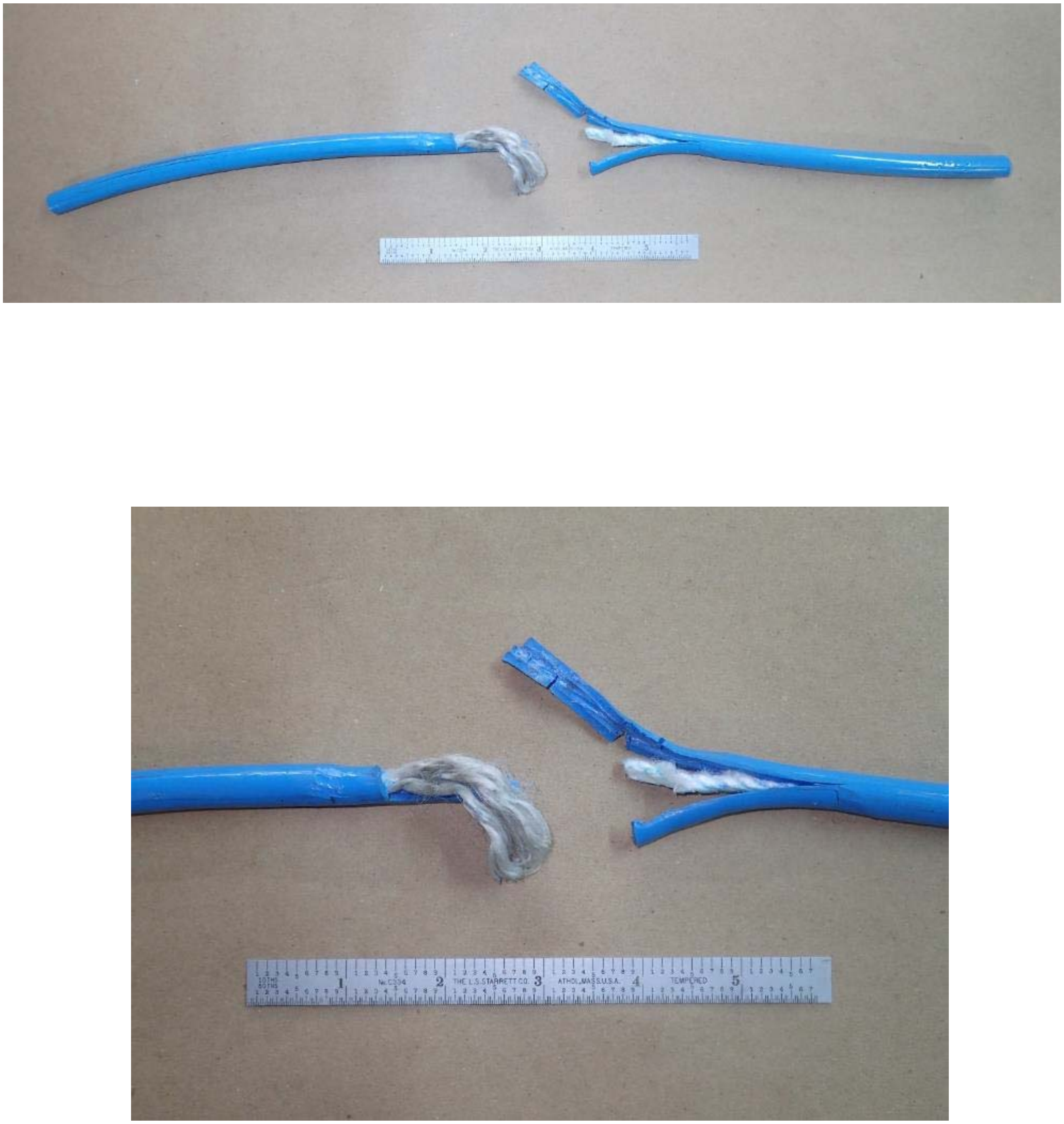


Figure 9. Views of the failed weld region of the IBEX belt that was available for examination during the first testing event at the ESI laboratory in Dallas, Texas. The outer ends of the pieces shown in the upper image had been cut to remove the failed weld from the remainder of the belt (which was stored at the Invenergy site).

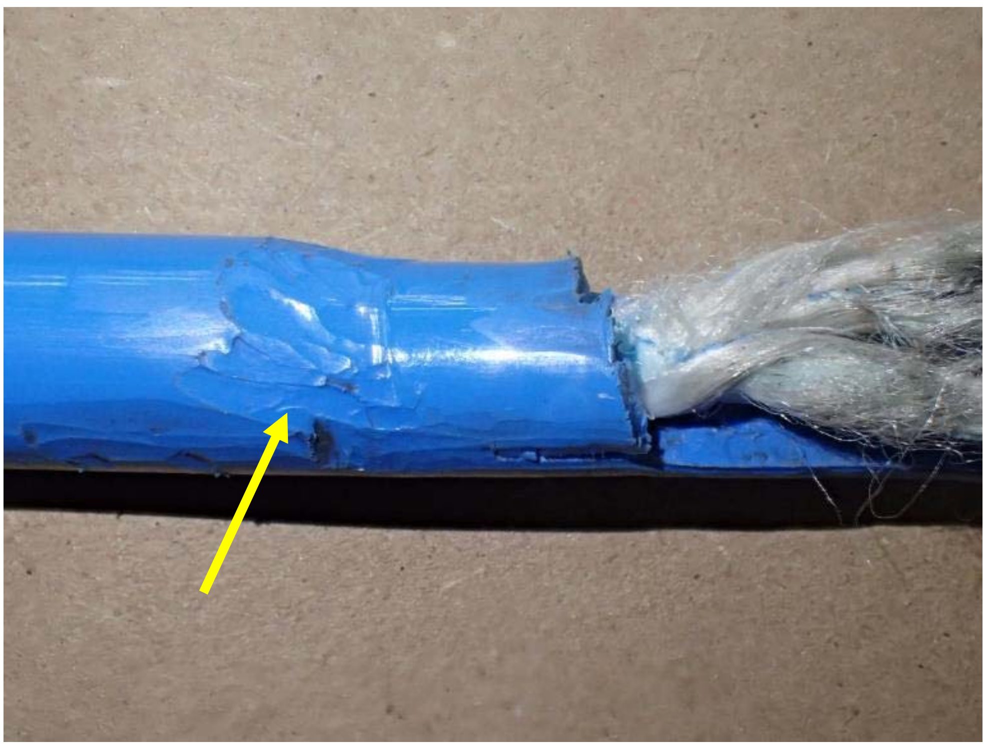


Figure 10. Additional close views of one side of the belt failure location. The surface cuts visible in the lower image are consistent with trimming of the belt after welding two ends together.

Figure 11. Additional close views of the other side of the belt failure location from that shown in Figure 10. The transverse line and surface cuts visible in the lower image are consistent with a weld seam and trimming associated with the welding process.

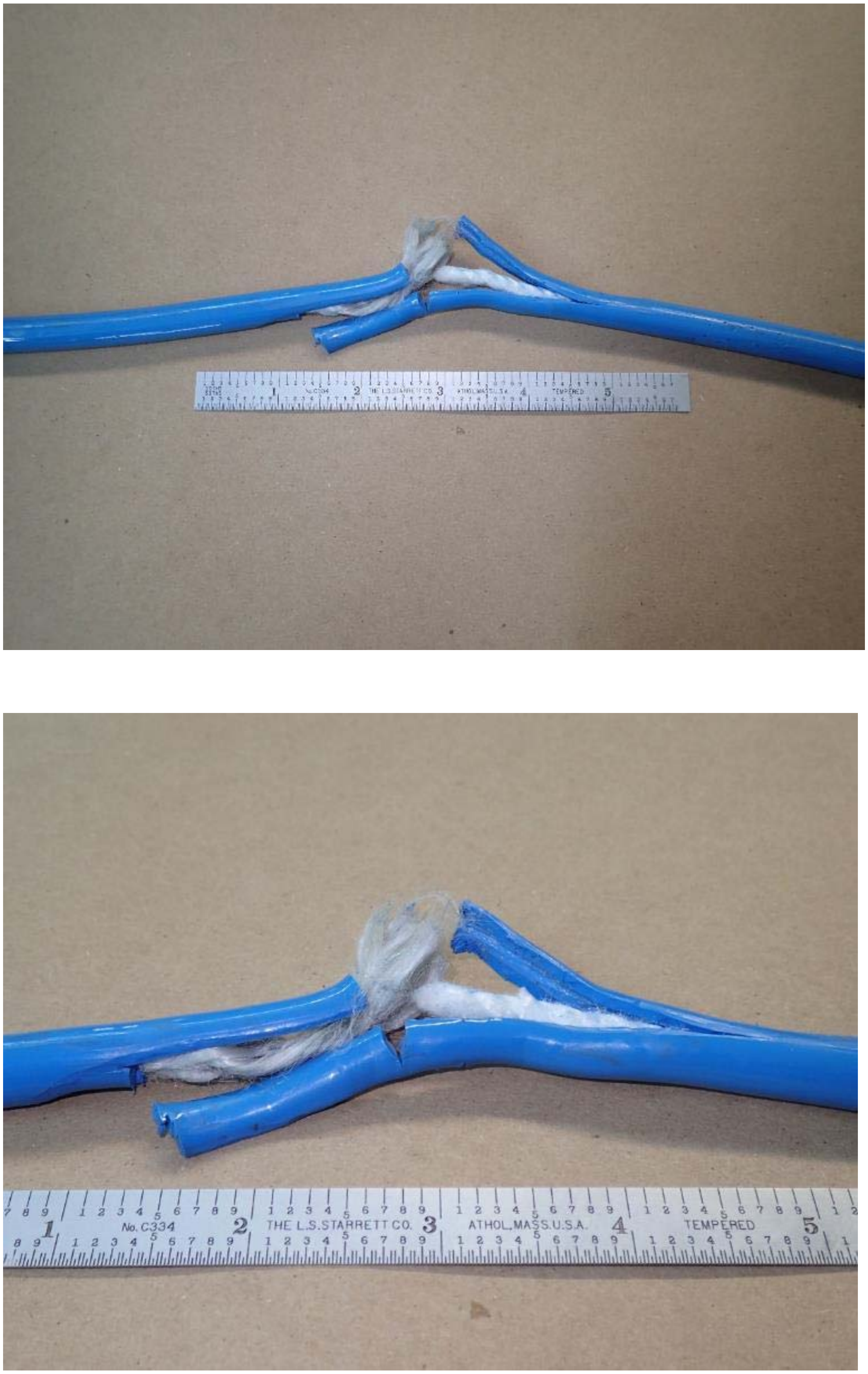


Figure 12. Views of the two IBEX belt segments after repositioning in the approximate pre-failure configuration.

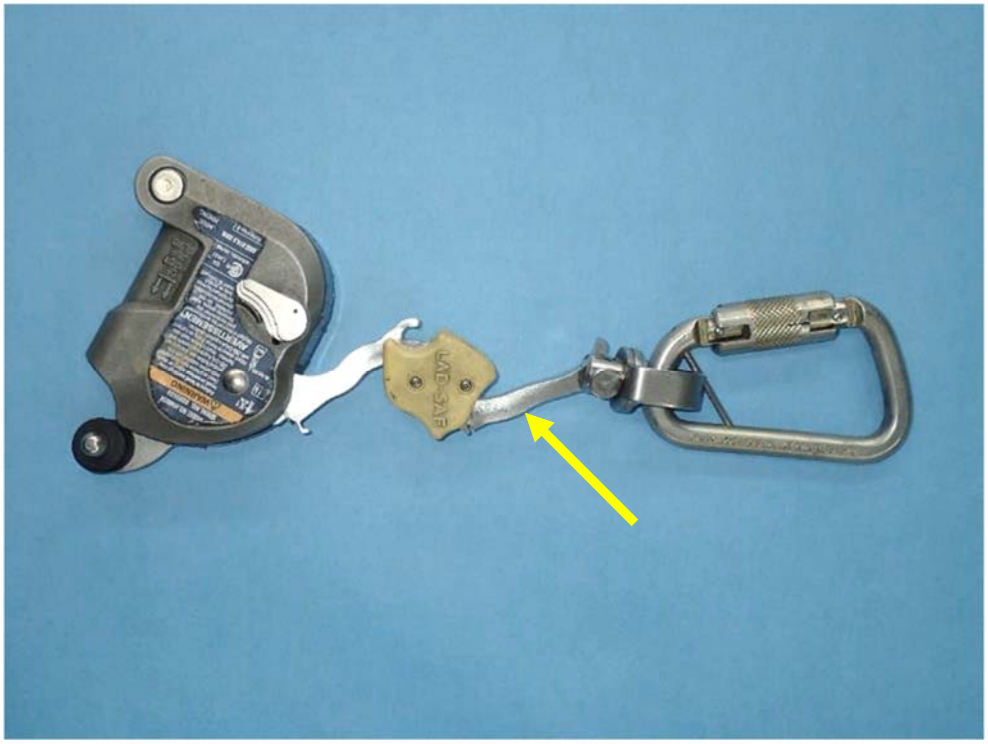


Figure 13. Views of the Lad-Saf X3 that Mr. Moore was reportedly using at the time of the fall incident, marked with Model No. 6160054 and Serial No. 0005580. In the upper image, the arrow indicates the location of the energy absorbing device, which has deployed (stretched).

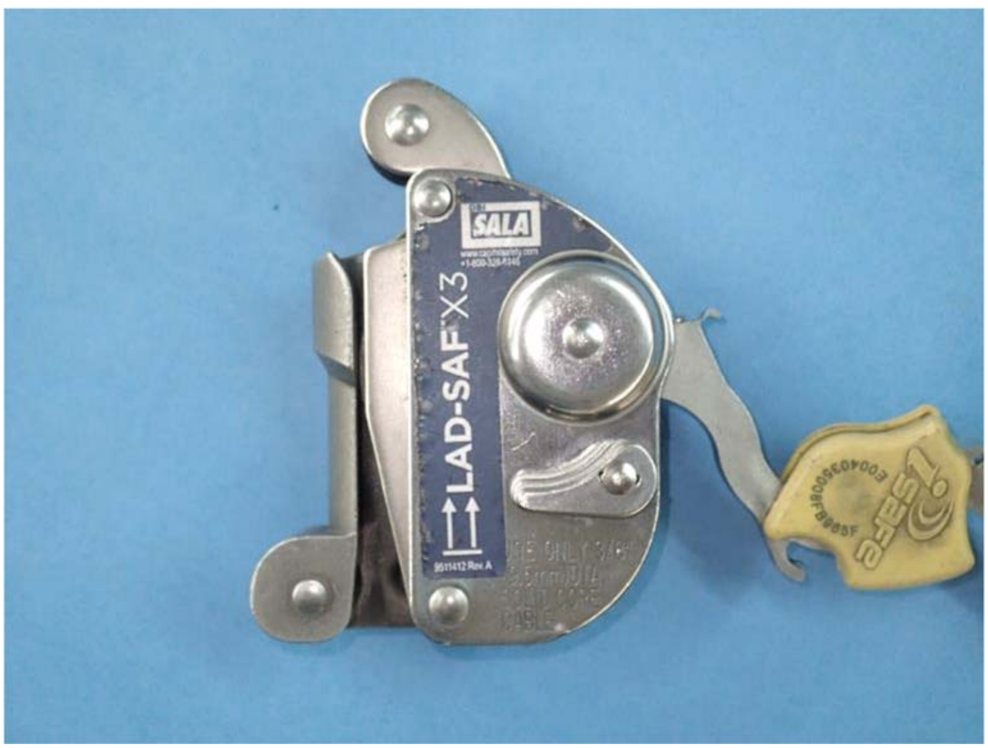


Figure 14. Additional views of the Lad-Saf X3 that Mr. Moore was reportedly using at the time of the fall incident.

Figure 15. Views of the IBEX climb assist belt (blue) and Tuf-Tug cable (metal) that were involved in Mr. Moore's fall incident, after transferring to the ESI laboratory facility in Dallas, Texas. The IBEX belt was in multiple pieces, including the smaller segments adjacent to the weld failure location.

Figure 16. Additional views of the IBEX belt at the ESI facility. The two segments from the failure location are indicated by the arrows.

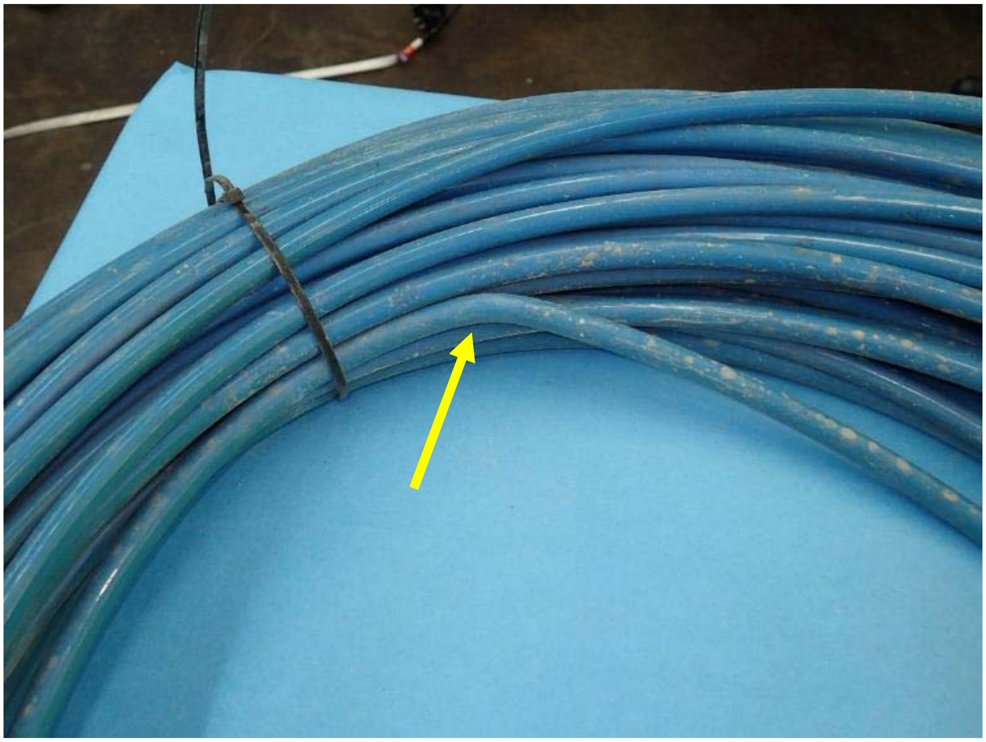


Figure 17. Views of two locations on the IBEX belt where deformation was present (permanent bends) are indicated by the arrows. The exact position of the belt at the time of failure, including the vertical location of the weld, was not determined.

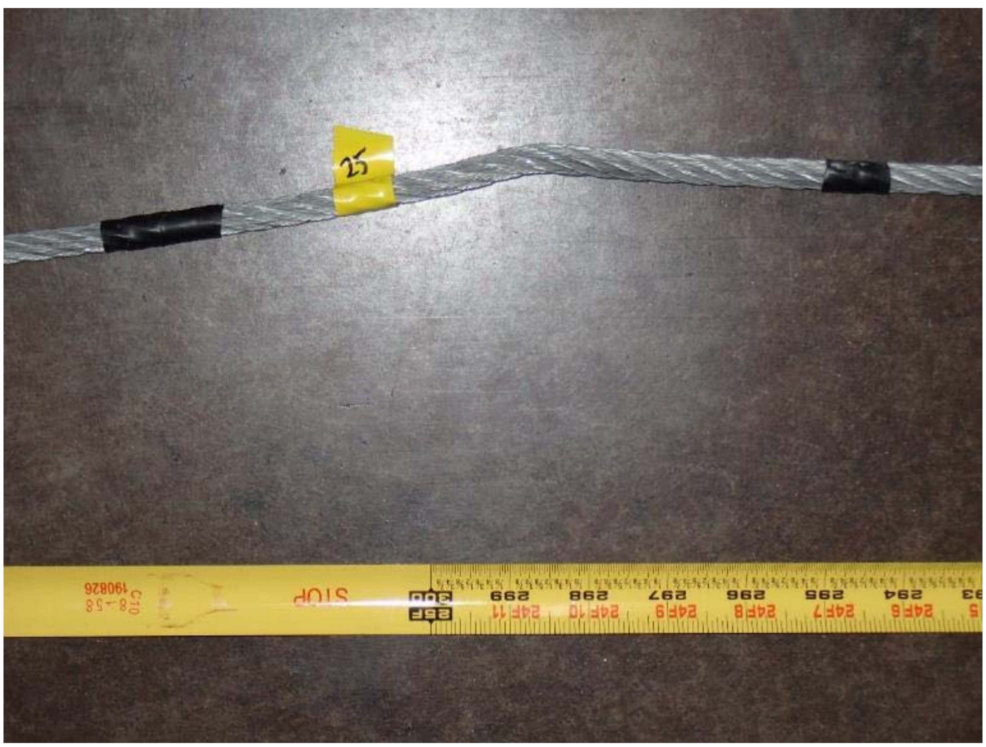
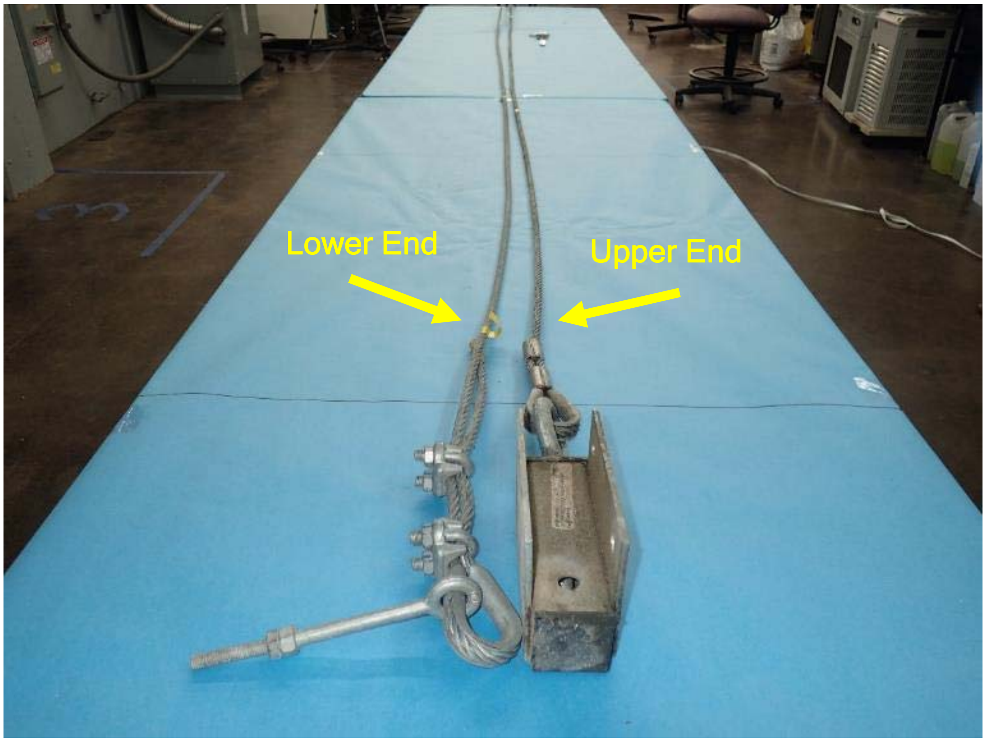


Figure 18. Views of the upper end of the Tuf-Tug cable (upper image) and a marked location with a kink approximately 25 feet from the upper fitting.



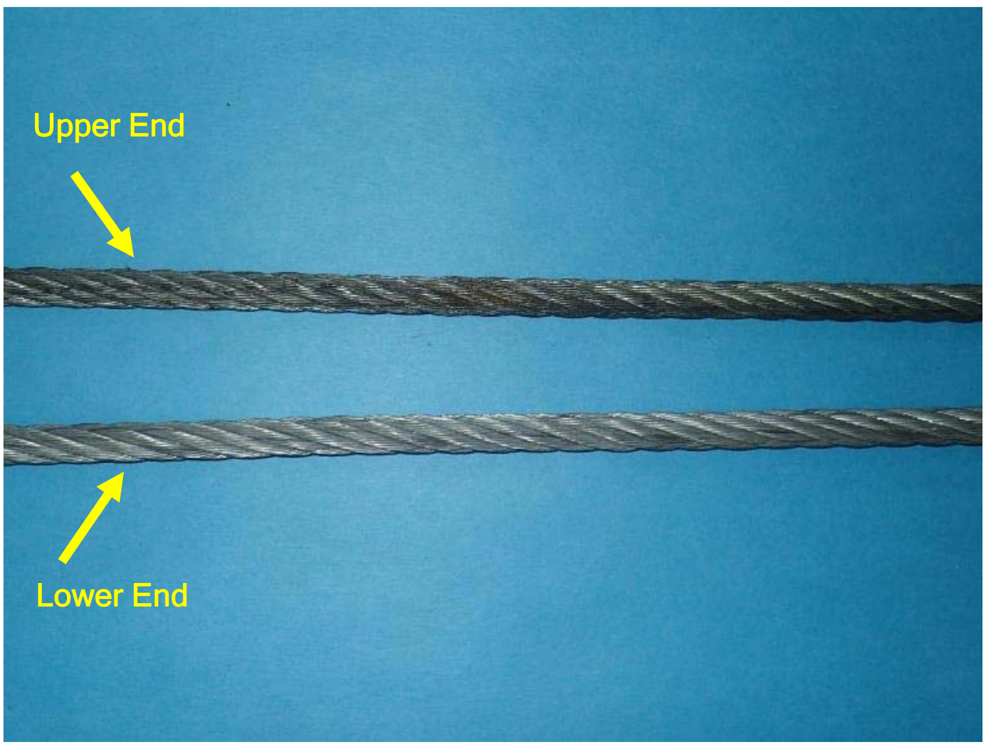


Figure 19. Views of the upper and lower ends of the Tuf-Tug cable involved in the fall incident. The upper end was darker in color as a result of a slight residue of an oily substance and deposits on the cable surface.

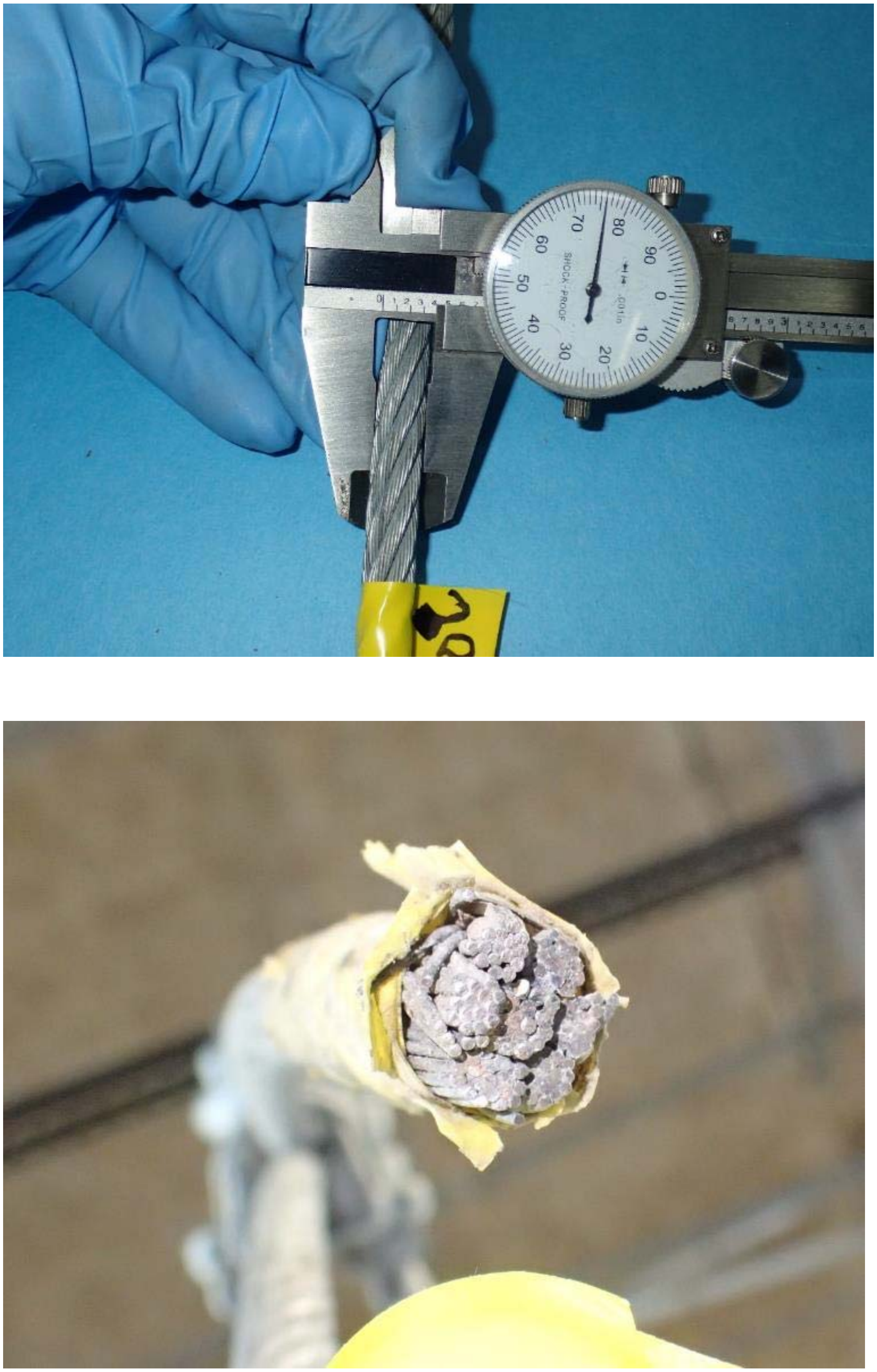


Figure 20. Views of a typical cable diameter measurement, which identified the cable as 3/8” diameter (upper image), and close view of the subject cable’s 7x19 construction (lower image).

Figure 21. Views of Tuf-Tug hardware components that were stored with the cable. The components were intact with minor indications of wear.

Figure 22. Views of an ESI technician performing manual tests on the subject Lad-Saf X3 sleeve (upper image) and the cable segment used to perform additional tests of the subject and exemplar sleeves (lower image). In the lower image, the lower end of the Tuf-Tug cable from the tower was attached to the ceiling and a weight was suspended from the cable to keep it tight during the testing.

Figure 23. Views of the subject Lad-Saf X3 sleeve being tested on the temporary cable setup.

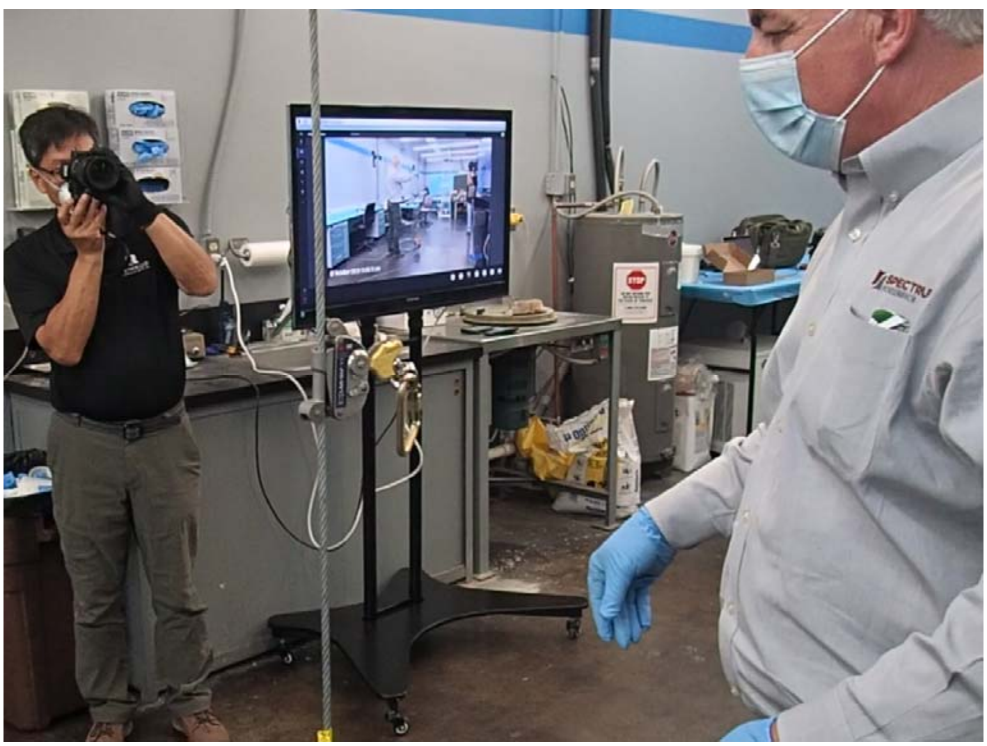
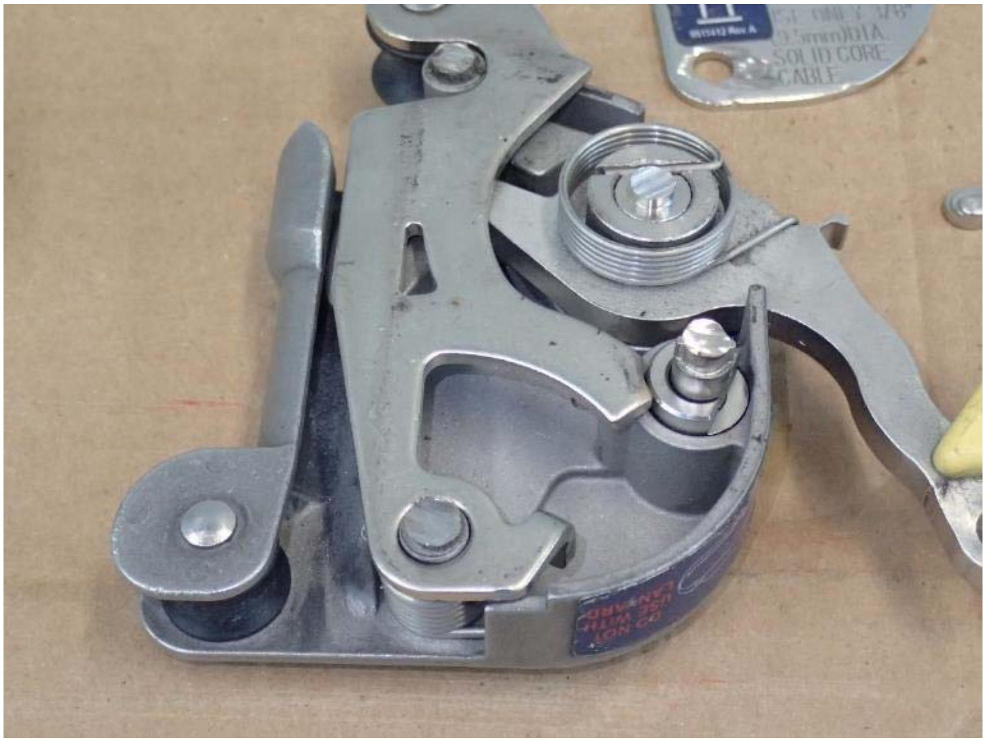


Figure 24. Views of an exemplar Lad-Saf X3 sleeve being tested on the temporary cable setup.

Figure 25. Views of the subject Lad-Saf X3 sleeve during a dynamic test that was performed by taping the locking arm in the up position, attaching a 10 lb weight to the carabiner, and dropping the weight. When the weight was dropped, the sleeve locked onto the cable, causing the weight to pull the locking arm down and stretch the tape.

Figure 26. Views of the subject Lad-Saf X3. In the upper image, the rivets are being ground to permit opening of the sleeve, and in the lower image, the rivets have been ground off.



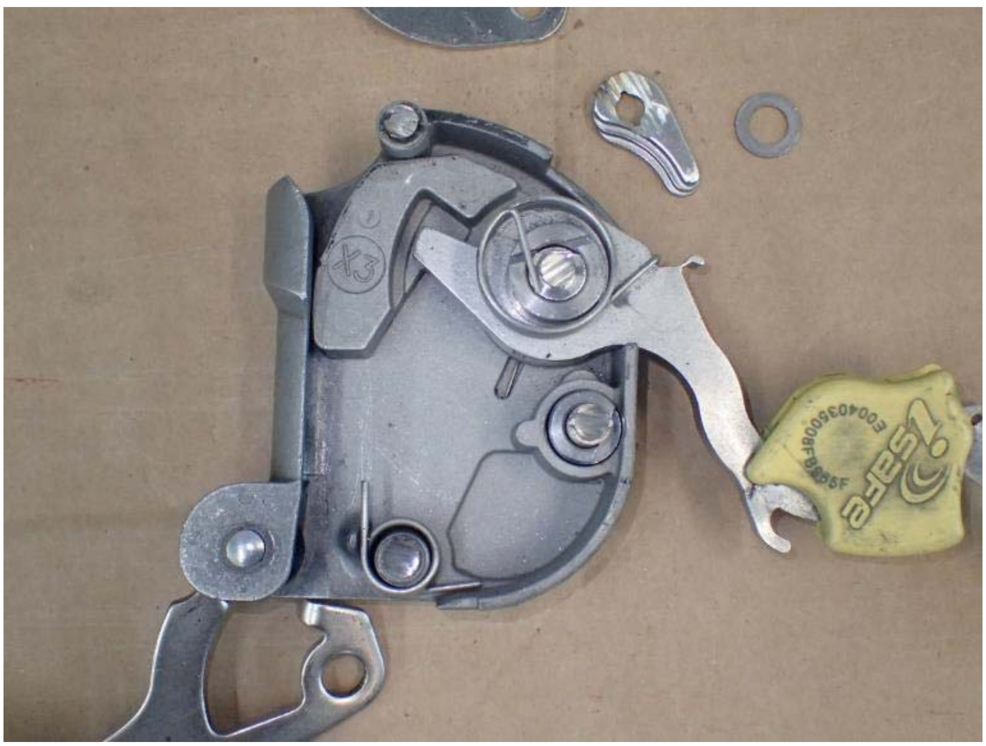


Figure 27. Views of the Lad-Saf X3 after removing the cover plate. Internal parts were intact and in place with no evidence of cracking.

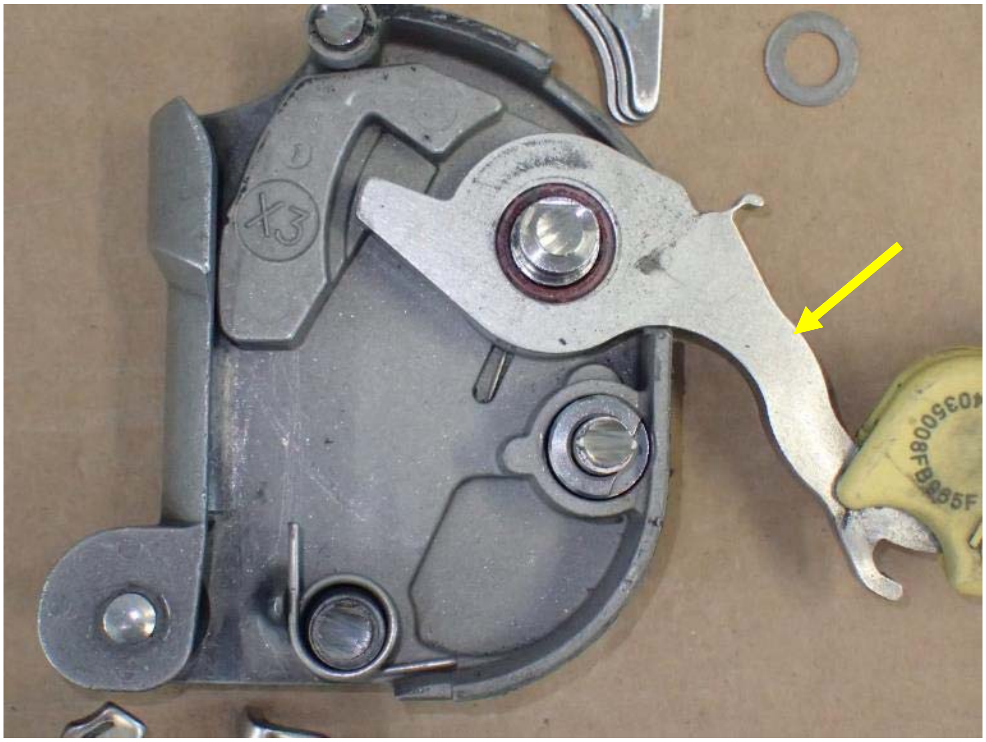
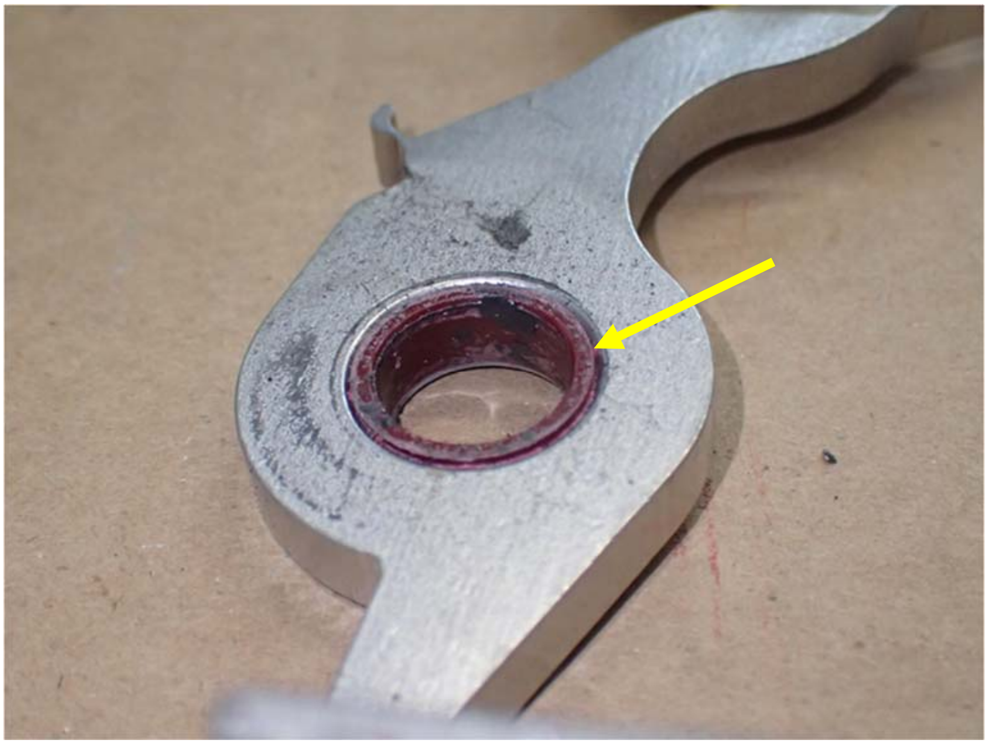


Figure 28. Additional close views of the Lad-Saf X3 components during the disassembly process. Note that the energy absorber (indicated by the arrows) is expanded and deformed as a result of the deployment event.



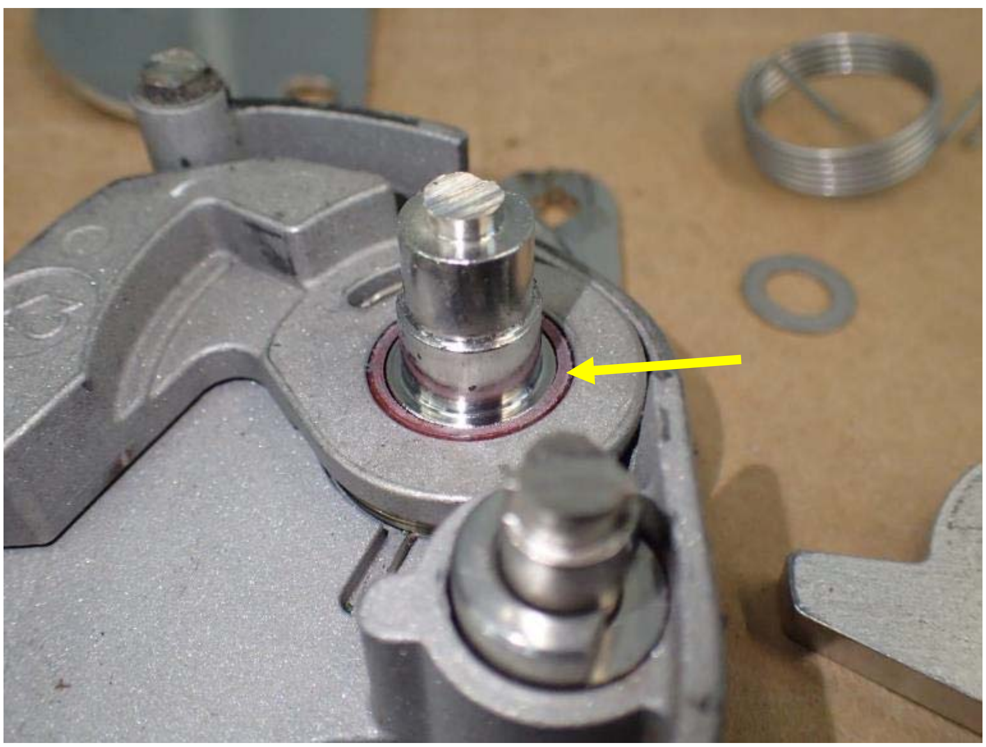


Figure 29. Additional close views of the Lad-Saf X3 components during the disassembly process. In these images, the red polymeric bushings in the energy absorber and cam are indicated by the upper and lower arrows, respectively.

Figure 30. Close views of both sides of the polymeric washer that was installed between the energy absorber and cam bushings.

Figure 31. Close views of the cam and bushing after removal from the Lad-Saf X3.

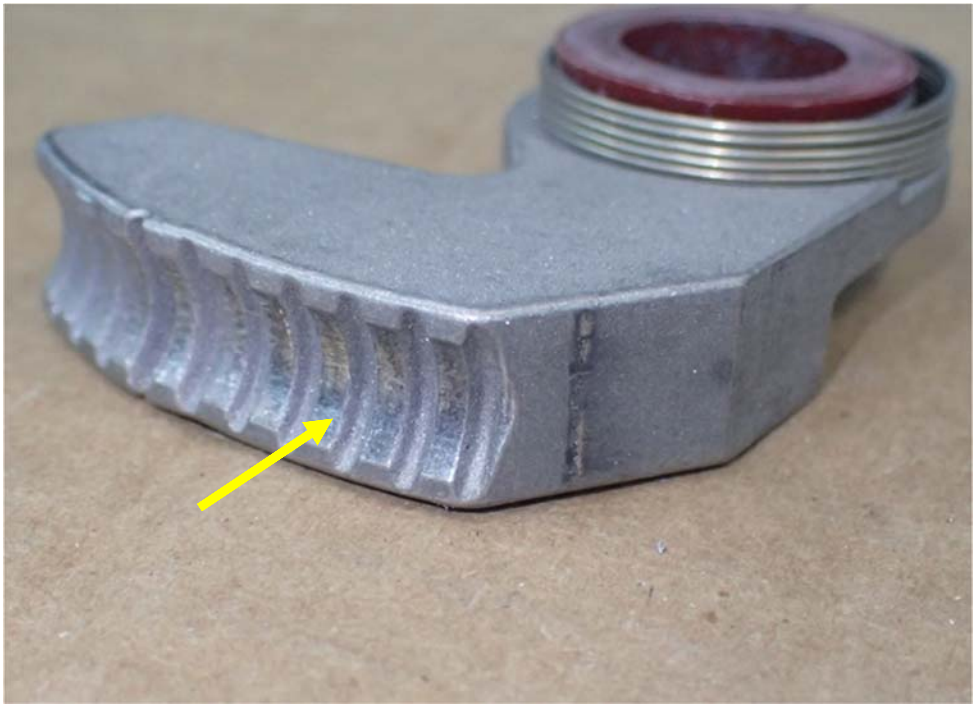


Figure 32. Additional close views of the cam after removal from the Lad-Saf X3. The cam surface appeared to have witness marks as a result of contact with the cable (arrows).

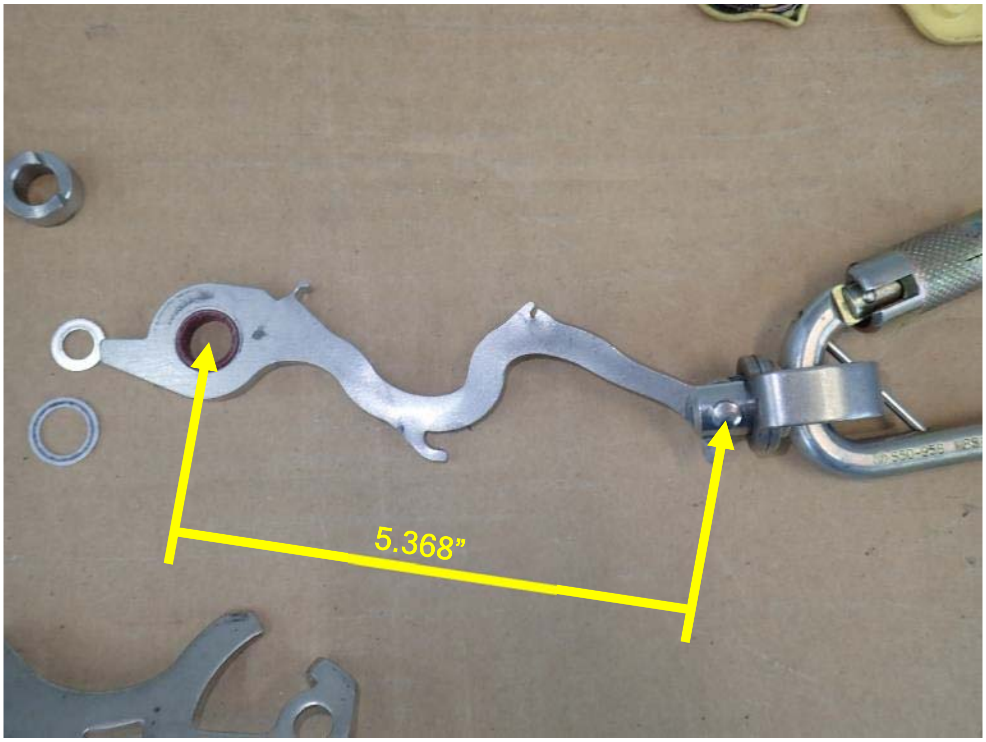


Figure 33. Views of the deployed energy absorber (upper image) and cover (lower image) after removal from the Lad-Saf X3. The extended length between pins was measured to be 5.368 inches, as indicated, and the deformed absorber was slightly twisted.

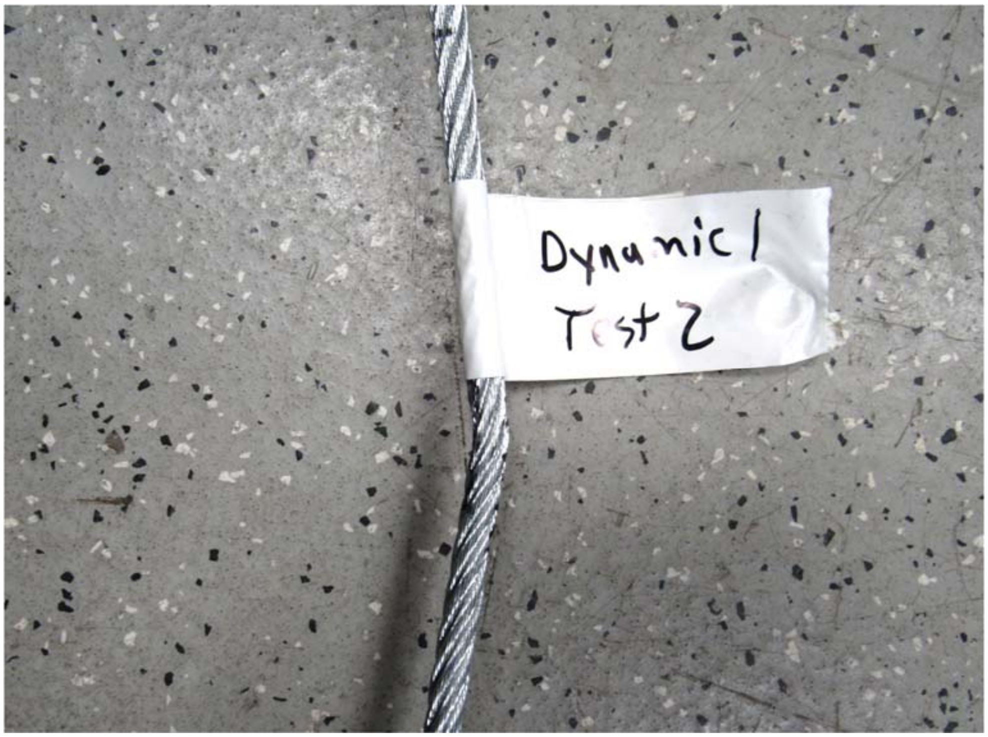
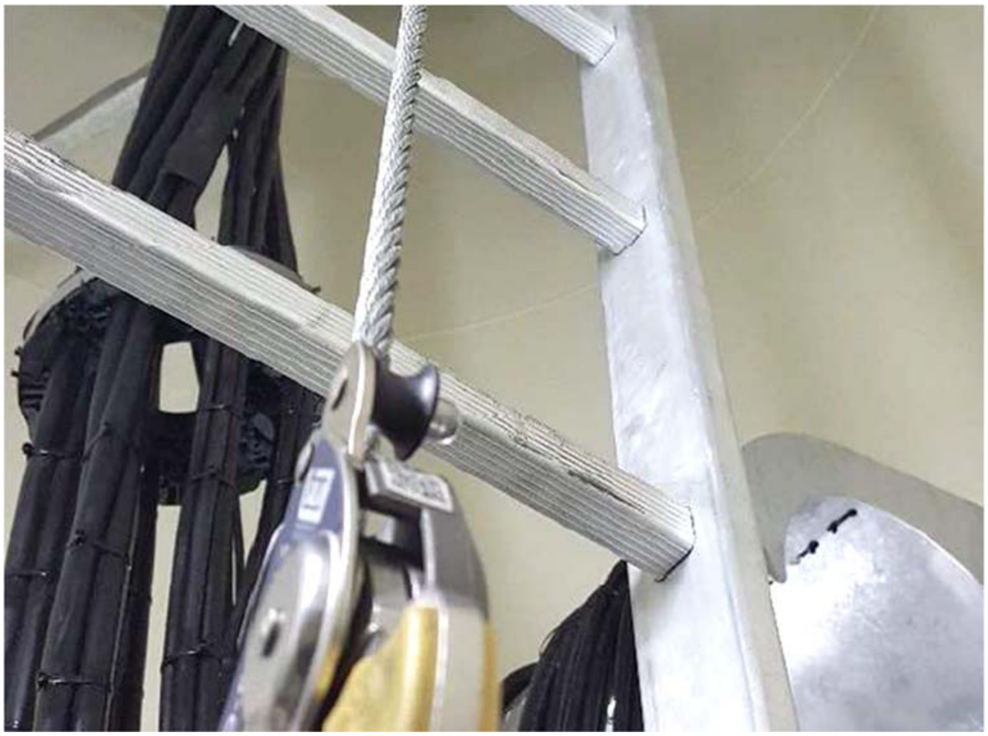


Figure 34. Views of the cable deformation produced by the first drop test performed by 3M on October 30, 2020 (upper image, provided by 3M), and the cable deformation produced by Mr. Moore's fall incident (lower image, provided by Invenergy).



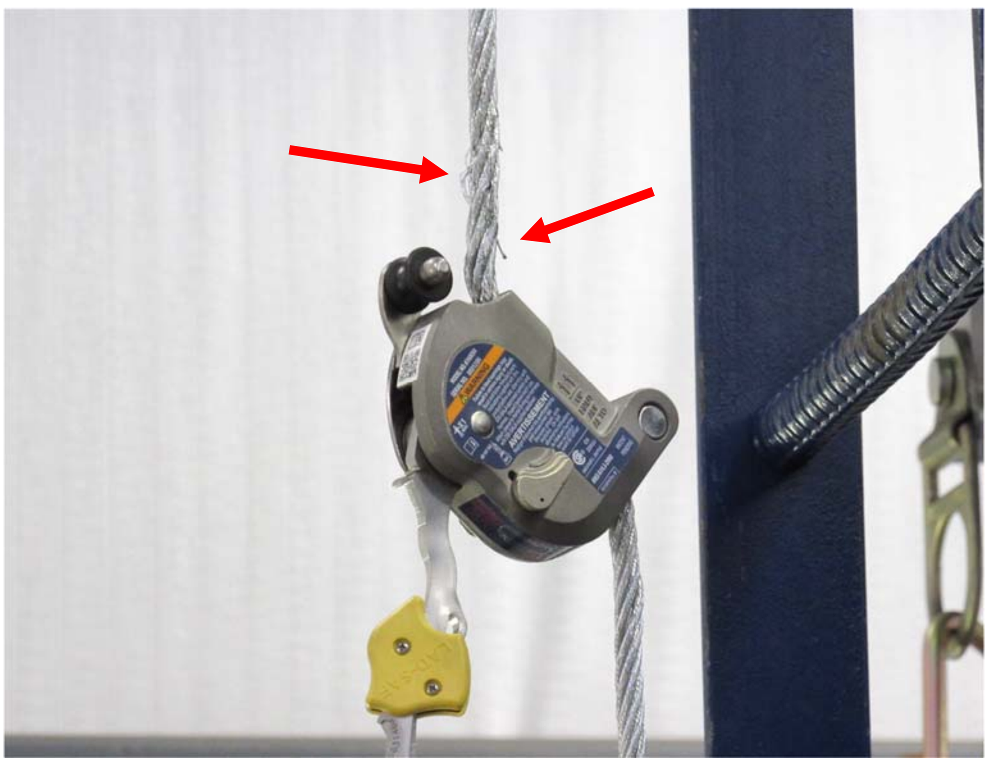


Figure 35. View of the Tower 41 cable (upper image) showing the location where the subject X3 sleeve was locked onto the cable (image provided by Invenergy), and view of the X3 sleeve tested on October 30, 2020, by dropping an anthropomorphic mannequin 16-1/2 feet (lower image). In the lower image, damage to the cable is evident (image provided by 3M).

Figure 36. Additional views of the damaged cable and broken wire strands associated with the 16-1/2 foot drop test performed on October 30, 2020 (images provided by 3M).

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Dr. McDonald is a mechanical engineer with over 20 years of experience in metallurgy, failure analysis, and accident reconstruction. Prior to entering the consulting business, Dr. McDonald conducted research in metallurgy, and taught undergraduate courses in mechanical engineering and material science. He also worked as a consultant on projects associated with the evaluation and design of materials and components for mechanical and electrical applications.

Dr. McDonald's consulting background has provided him with extensive experience in the evaluation of material and product failures, and the analysis of utility, industrial, construction, and marine accidents. With regard to metallurgical failures, he has experience in fractography, metallography, and microscopy, and is able to combine the principles of engineering and materials science in the identification of causative factors, including fabrication flaws, mechanical damage, corrosion, abnormal loading conditions, etc. His experience includes more than ten years of work in the investigation of power plant component failures, including tubing, piping, steam turbine components, industrial fans, fasteners, and related balance of plant equipment. He has also been involved in multiple large-scale root cause analyses (RCA's) related to power plant failures.

Dr. McDonald has provided expert testimony in more than 30 deposition and trial settings, and is the author of more than a dozen articles and reports on low temperature materials and the methods used to study material properties at low temperatures; two of his publications have won awards. Dr. McDonald is also co-author of two patents concerning aluminum alloys.

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Publications

L.C. McDonald and K.T. Hartwig, "Creep of Pure Aluminum at Cryogenic Temperatures," Advances in Cryogenic Engineering - Materials, Vol. 36B, p. 1135, Plenum (1990). (Received a "Meritorious Paper" Award at the 1989 International Cryogenic Materials Conference).

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"High Purity Aluminum Conductor Used at Ultra Low Temperature," (This Patent Deals with Texture and Orientation) Appl. No. 08/088,032, granted November 21, 1997.

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Related

Dr. McDonald has reviewed articles for Cryogenics and Proceedings of the International Cryogenic Materials Conference, aided in the organization of two International Cryogenic Materials Conferences, and Chaired or Co-chaired sessions of two International Cryogenic Materials Conferences.